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TIMBER MARKETS AND FUEL TREATMENTS IN THE WESTERN U.S.

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ABSTRACT. We developed a model of interrelated timber markets in the U.S. West to assess the impacts of large-scale fuel reduction programs on these markets, and concomitant effects of the market on the fuel reduction programs. The linear programming spatial equilibrium model allows interstate and international trade with western Canada and the rest of the world, while accounting for price effects of introducing softwood logs to the market. The model maximizes area treated, given fire regime-condition class priorities, maximum increases in softwood processing capacity, maximum rates of annual treatments, prohibitions on exports of U.S. and Canadian softwood logs from public lands and a fixed annual treatment budget. Results show that the loss to U.S. private timber producers is less than the gains for timber consumers (mills). States receiving more treatments when spending is not constrained by state proportions include Idaho, Montana, New Mexico and Oregon. When only the wildland-urban interface is treated, California, Oregon and Washington receive more treatments. Utah and Colorado receive more treatments when low risk stands are included.

KEY WORDS: Wildfire, mechanical treatments, spatial equilibrium, welfare.

Introduction. Recent increases in wildfire suppression expenditures and financial losses resulting from large fire events have increased the interest in developing policies to address forest health conditions in western U.S. forests. One particular concern is that previous fire suppression and prevention, combined with climate change, has led

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to hazardous fuel accumulations in many forested areas (Parsons and DeBenedetti [1979], Bonnicksen and Stone [1982], Parker [1984], Chang [1996], Harrod et al. [1999], Arno et al. [1997], Skinner and Chang [1996]). A second concern is encroachment of human populations into these forests, often referred to as the wildland-urban interface (WUI), which creates the potential for increased loss of private property during wildfire events. One proposed solution addressing both of these concerns is to reduce fuel accumulations in the WUI and surrounding lands using mechanical treatments.

The increase in fuel treatments has been promoted in the National Fire Plan[1] and the Healthy Forests Initiative (HFI)[2] which Congress modified and passed, as well as the Healthy Forests Restoration Act[3]. The USDA Forest Service adopted the Comprehensive Strategy and Implementation Plan[4], partly in response to criticisms from the GAO regarding its lack of cohesion in developing a fuels reduction strategy (U.S. General Accounting Office [1999]). Current funding for fuel treatment programs on both public and private lands exceeds $1 billion per year, although the funding for mechanical treatments with biomass product removals is considerably smaller.

One effect of implementing these treatment programs is the de facto removal of limits on federal harvests, in particular federal harvests that would result in below-cost timber sales. It is possible that areas most in need of treatment are also the areas with the smallest proportion of high quality wood and the most expensive treatment costs. Thus, these treatments would require large subsidies in many areas because the treatments would not provide adequate products for sale while simultaneously reducing fuels.

Large-scale biomass removals programs done to lower wildfire risks and associated potential damages on National Forests, other government forests and private lands may have economic impacts across a range of temporal, spatial and sectoral scales, including short- and long-run impacts on economies, impacts on local, regional and national forest product markets, and effects on other economic sectors in and around the removal zone (Mercer et al. [2000]).

The treatments will affect the markets for privately supplied timber by increasing the supply of some products, thus lowering the available prices and hence the quantity offered by private producers. In a treatment program that maximizes treatment acreage subject to a subsidy computed as the costs of treatments minus revenues accrued from materials removed and sold, the market price effect could reduce the ultimate acreage treated. This paper presents a model wherein we maximize acres treated given a subsidy, not allowing for offsetting treatment costs with treatment revenues. Instead, we assume that treatment revenues go to the Treasury and hence do not offset treatment costs.

The magnitude of the timber market effects will depend on the current state of the market, including excess wood processing capacity. Some of these treatments would require a complete subsidy. That is, there would be no revenues from products removed. Others would pay at least partially for themselves through sales of timber products. Thus the amount of fuel treatment that could be accomplished would depend on the proportion of the treatments receiving subsidies, and the subsidies would influence timber markets, and thus timber prices.

Two recent studies have addressed large scale fuel treatment programs without directly addressing issues of market welfare and prices. A Strategic Assessment of Forest Biomass and Fuel Reduction Treatments in Western States (Western Biomass Assessment) (Rummer et al. [2003]) quantified the biomass available for treatment in the western U.S. by state. This study examined the potential biomass available by using current prices, costs derived from a treatment model and inventory data from USDA Forest Service Forest Inventory and Analysis. A second study (Fried et al. [2003]) evaluated the potential location of new biomass processing facilities in Southern Oregon. Fried et al. [2003] evaluated conditions and treatable volumes in the region, as measured on Forest Inventory and Analysis plots. Although their study did find large treatable volumes on the ground, some of which could be economically treated, investment potential hinged on the assumption that prices were not endogenous to treatment quantities.

Our research extends the above analyses by directly addressing the market impacts of alternative program scales. To account for market price effects, we use a spatial equilibrium market model of twelve western states and other trading partners, and assess the outcome of a \$1 billion fuel treatment program. States included in the analysis are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, western South Dakota (the Black Hills), Utah, Washington and Wyoming. The model objective is to maximize treated acres in national forests, allowing for shifts in private timber harvest. After treated acres (given price effects) are maximized, social welfare is maximized as a secondary objective, allowing consuming mills to purchase wood and private producers to sell wood across state and national borders. The treatments by state, forest type and condition class, and the welfare implications of alternative subsidy programs, are described and discussed. We also analyze how a national forest lands mechanical fuel reduction treatment program limited to the wildland-urban interface would affect timber markets and treatment applications.

Literature and methods. Timber markets of the western U.S. have long been dominated by harvests from public lands, but the situation has changed in the last decade (Haynes et al. [2001]). National forests of the West provided nearly half of all timber harvested during the period 1950–1985. Since the late 1980s, however, harvests in the West are dominated by industrial and nonindustrial forestland owners. Markets in the region have contracted overall, and timber outputs in major producing states have declined. Large-scale biomass removals could result in a near doubling of timber output in many parts of the fire-prone West.

Large changes in the amount of wood on local markets can affect the welfare of timber producers and timber consumers by shifting supply (Holmes [1991]). Outward shifts in supply decrease prices and increase overall welfare. However, such shifts can have differential impacts on various producer and timber consumer groups, especially when the outward shift in supply results in a contraction in demand for alternative products. Of particular interest is the effect of such shifts on private timber producers, whose outputs compete directly with outputs of national forests (Adams et al. [1996]).

Outward shifts in supply such as those associated with salvage removal programs are often short-run, affecting local markets for only a few months to a couple of years (Holmes [1991], Prestemon and Holmes [2000]). If such outward shifts in supply are perceived by demanders to be temporary, then demand will not increase and market responses to supply increases are limited by local mill production capacities and markets for mill outputs. In the case of a short-run supply shift, timber consumers gain but producers, especially producers not participating in a biomass reduction program, may be harmed. This effect is similar to programs such as tree planting incentives which are intended to increase future timber supplies (Boyd and Hyde [1989]). If supply shifts are perceived as permanent, then arbitrage can lead to outward demand shifts that return prices to normal and increase economic welfare generally within the sector.

Timber supply in areas of significant federal timber harvests can be described as consisting of two components: price-responsive private supply and policy-driven public supply. Increased public land timber harvests benefit mills but harm private timber suppliers by driving down the price of timber. In the calculation of timber market effects of treatments, economic surplus is estimated using techniques described by Just et al. [1982]. These techniques have been applied frequently in forestry, e.g., Holmes [1991], Wear and Lee [1993].

From the perspective of public timber supply, there are at least two possible outcomes for the timber market with a biomass removals program in place, and these two outcomes depend on whether biomass removals substitute for regular removals from public lands or merely add to them. There would be no immediate market effects on producers or timber consumers in the short-run if (1) product removals from biomass treatments substitute for regular harvests and (2) the costs per unit to get the product to markets are the same and (3) the mix of products going to markets remains the same. Over the long run, the programs would affect residual stands, including growth rates, final products obtained from a different inventory structure and wildfire salvage volumes obtained from the forests under an altered wildfire risk.

In this analysis, biomass removals are assumed to supplement regular public harvests. The price effects of these programs would depend on how fast timber demand can adjust to a larger supply obtained from the treatments. Large, brief programs of biomass removals will depress prices, harming private producers and benefiting wood product manufacturers (the timber consumers).

From the perspective of timber demand, the impact of biomass removals programs on markets will depend on the demand response, either (1) affecting trade across regions and the process of spatial arbitrage and/or (2) altering capacity utilization rates at existing mills and/or (3) influencing the creation of new capacity in the vicinity of the treatment zones. The current study evaluates only the short-run situation where local demand stays constant, thus market responses (1) trade and (2) capacity utilization will be incorporated. Local price effects may be moderated if the products from treatment programs can be profitably moved outside the region. Such movement, however, would have economic effects outside the region that should be accounted for (Murray and Wear [1998]). Recent research (Prestemon and Holmes [2000], Nagubadi et al. [2001], Bingham et al. [2003]) has shown that low product values and high shipping costs or market inefficiencies can limit the transmission of local market changes to more distant markets.

Figure 1 illustrates the welfare, price and quantity effects arising from a fuels treatment program in a market with both public and private harvests but no trade. Private timber supply is price-responsive, increasing in quantity with increasing price. Public supply is symbolized by a vertical line, S_0^G. Price in the market for timber is set where the curve representing the sum of private supply and public supply, S_0, intersects the timber derived demand curve, D, at point a, resulting in the equilibrium price P_0 and quantity Q_0 without a fire-related biomass removals program. Producer economic surplus is the area above the private supply curve and below price, area P_0ac. Economic surplus accruing to timber consumers is the area above price and below the demand curve, area daP_0.

Where the harvests from a large scale program of fire-related biomass treatments on national forests add to regular removals, thus not substituting for regular harvests, the government supply curve shifts to S_1^G, so that total supply shifts outward, to S_1. The total quantity offered with the shifted supply curve, including private supply, is Q_1, and price drops to P_1. Producer economic surplus for private timber producers is area feb, while government revenues from treatments and regular harvests amount to area P_1fe. Surplus accruing to timber consumers is larger than without the biomass removals and is now area dbP_1. Note that the producer surplus accruing to private producers is reduced unambiguously by such a treatment program, as the market price declines and their volume sold shrinks[5]. Also, these changes might apply to producers and consumers locally, but the opportunities to ship product outside a region of fuel treatments can reduce the welfare effects of such a program. Emphases on different parts of a treatment region can also have anomalous effects on consumers and

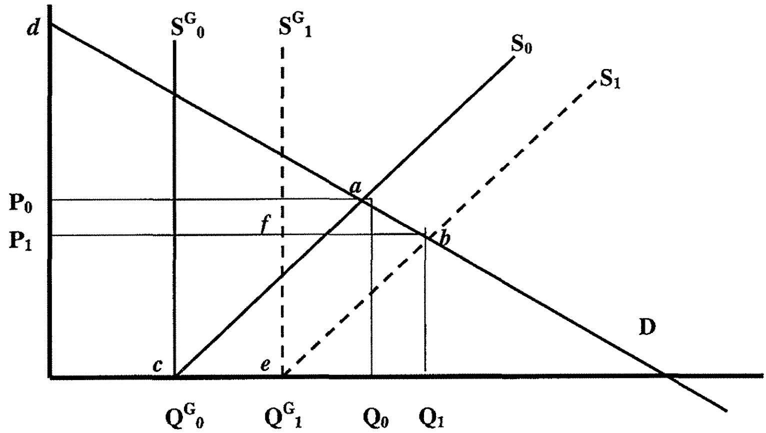


FIGURE 1. Timber market structure in areas with public timber harvests, with a representation of the effects of a biomass removals program.

producers. If treatment programs effectively substitute less valuable treated material for more valuable untreated material, provided that the government subsidizes such treatments, consumers may be left only marginally better off and producers much worse off.

If supply shifts past the point where demand intersects the horizontal axis, then producers lose all timber market surplus—they sell no timber, as the market price for timber is zero—and public landowners get no value. In fact, the public would have to pay timber harvesters to remove the biomass. Timber consumers would still gain, however, as wood is provided to them at no cost or they would need to be paid to cut it[6].

A similar story could be told about benefits accruing to producers and consumers if, instead of new capacity developing locally, demand shifts outward as a result of expanded wood product exports out of the region to other parts of the United States or abroad. The timber consumers benefited in that case would reside outside of the treatment region.

Another component of market analysis is identification of intermarket relationships. If markets are integrated, that is, if local market shocks are transmitted, see Ravallion [1986], and biomass harvests are large, then the price effects of these harvests can be transmitted across regions, resulting in economic effects of these harvests that go beyond the treatment zone. Unless these intermarket relationships are understood and quantified, single market analyses would reach erroneous conclusions. One method of evaluating the degree of market linkages is by examining the costs of transfer of various forest products among producing and consuming markets. These are the methods outlined by Samuelson [1952] and Takayama and Judge [1964].

Data. The 12 states included in the model incorporate 13 forest types and are modeled as producing 4 softwood products which are grouped here as (1) ponderosa pine, including ponderosa pine (*Pinus ponderosa*) and sugar pine (*Pinus lambertiana*), (2) lodgepole pine (*Pinus contorta*), (3) other softwoods and (4) softwood chips. In the current model, the chip market uses a fixed price of $0.35 per cubic meter and is assumed to be not influenced by the treatment program[7].

The model allows for trade with other regions by adding western Canada and the rest of the world as two additional markets. Western Canada includes British Columbia and Alberta. The remaining Canadian provinces, the eastern and southern U.S., and all other countries are referred to as the rest of the world. Northern Alberta and Northern BC are modeled as lodgepole pine, southern Alberta as containing mainly ponderosa pine and BC as containing other softwood. Trade with the rest of the world is allowed only by the coastal states and easternmost states, while trade with Canada is allowed only by the northern border states. Exports of logs from public lands in both the western U.S. and from Canada are restricted by law and thus are constrained to zero in the model. Exports of logs from private lands are allowed from both countries. Import taxes on logs are set to zero, consistent with the North American Free Trade Agreement and the majority of U.S. and Canadian log export destinations and import sources.

Inventory and acres. Inventory volume and acreage data are from the Western Biomass Assessment (Rummer at al. [2003]) and consist of volumes and acres by major species group by state. These volumes were then proportionately assigned to the wildland urban interface (WUI) and to fire regime-condition classes (CC) by the proportion of the total area in each state in these classes. Wildland-urban interface area was calculated using wildland-urban interface maps provided directly by Radeloff (V. Radeloff, personal communication [May 2003]). Fire regime-condition class represents a broad scale determination of fire risk, where condition class represents the degree of departure from historical fire regimes, with CC 1 closest to historical and CC 3 furthest away from the historical fire regime.

Treatments are applied only to national forest timberland and less than 60 percent of the timberland is assumed harvestable, consistent with the Western Biomass Assessment (Rummer et al. [2003]). Our estimates of potentially treatable acres by state by condition class are in Table 1. This table also shows the proportion of treatable timberland in each state that is assumed to be in the wildland-urban interface.

Current production. Current harvest data were developed using the 1997 Forest Resources of the United States removals and product data (Smith et al. [2001]). Hardwood removals account for only 4 percent of all timber removals in the 12 states and were not further addressed in this study. The removals used as base data for the model are shown in Table 2. Removals are reported by national forest ownership and by non-national forest ownership and by major species group.

Base level mill capacities and timber production levels in the U.S. and Canada derive from Spelter and Alderman [2003] and were adjusted for each state to reflect non-included mills. Outside the U.S. and Canada, softwood log production and processing capacities were set at 100% and 110% of production, respectively, as reported by FAO [2004] for 2002.

Treatments. The fuel reduction treatment, applied to all 13 forest types and 3 condition classes, removes volume on a stand to reduce stand density to 30 percent of maximum stand density index for that forest type and ecoregion. This treatment removes trees from all size classes, concentrating most removals in the small to mid-sized diameter classes. The prescription had no upper diameter limit on removals. Fiedler et al. [2001] found that removals from all diameter classes had more effect on reducing fire risk measures than did removals from only the smaller diameter classes. The SDI prescription is an 'average' treatment that allows analysis of all western forests at an aggregate

TABLE 1. National forest timberland acres, proportion treatable, treatable acres by fire regime-condition class, and proportion in the wildland urban interface.

State	Total timberland acres	Proportion treatable	Treatable acres by fire regime-condition class			Proportion of acres in WUI
			CC1	CC2	CC3	
Arizona	2,138,835	0.51	58,022	444,693	780,586	0.05
California	3,359,300	0.40	435,569	724,961	855,050	0.18
Colorado	5,510,098	0.45	1,324,486	1,122,447	859,127	0.06
Idaho	10,227,734	0.51	1,292,517	3,139,812	1,704,311	0.01
Montana	9,471,629	0.51	1,413,542	2,404,950	1,864,486	0.01
Nevada	146,892	0.58	23,401	21,914	42,820	0.03
New Mexico	1,938,855	0.40	129,431	403,645	630,237	0.02
Oregon	8,373,389	0.40	410,194	2,172,229	2,441,611	0.04
South Dakota	674,192	0.47	1,032	101,560	301,924	0.01
Utah	2,753,506	0.48	1,143,037	463,621	45,445	0.04
Washington	3,151,848	0.36	475,553	1,083,718	331,838	0.12
Wyoming	2,918,809	0.43	929,341	608,712	213,231	0.01

TABLE 2. Removals from national forests and all other ownerships by major species group by state.

	Non-national forests			National forests		
State	Ponderosa pine	Lodgepole pine	Other softwood	Ponderosa pine	Lodgepole pine	Other softwood
	Thousand board feet					
Arizona	29,204	0	8,160	11,036	0	3,084
California	411,447	37,702	1,599,891	78,602	7,203	305,640
Colorado	3,589	5,433	22,027	1,356	2,053	8,324
Idaho	64,307	60,189	473,451	24,301	22,745	178,917
Montana	41,693	89,015	282,545	15,756	33,639	106,774
Nevada	1,091	433	1,725	412	164	652
New Mexico	16,578	0	12,310	6,265	0	4,652
Oregon	272,149	44,563	2,484,729	29,774	4,875	271,841
South Dakota	13,002	0	6,770	23,207	0	12,084
Utah	1,701	1,501	14,835	643	567	5,606
Washington	151,403	42,757	2,515,421	16,564	4,678	275,199
Wyoming	5,479	9,355	19,473	2,070	3,535	7,359

level. Actual treatments for stands are not expected to correspond to these prescriptions and should be designed for each stand using information that is not available in the Forest Inventory and Analysis database.

Although many mechanical fuel treatments will not remove any products, these treatments are not discussed in this analysis as they will not have any market effects. It is also possible that treatments will be chosen that will remove some products and leave non-merchantable biomass on site. The treatment applied in this model does not allow for partial product removal from the stand. Only sawlogs were modeled in this analysis, and products were merchandized as in the Western Biomass Assessment (Rummer et al. [2003]).

Costs and prices. Product prices were derived from National Forest System Cut and Sold reports for the second quarter of 2003[8] and are shown in Table 3. Regional prices were adjusted by the percentage of harvest from each species group to provide species prices. Prices differ by state and major species group, ranging from a low of $39 per thousand board feet (mbf) in Arizona and New Mexico for lodgepole pine to a high of $528/mbf in Oregon and Washington for ponderosa pine. Treatment costs are determined using the methodology of the Western Biomass Assessment (Rummer et al. [2003]), Table 3. The STHarvest model (Hartsough et al. [2001]) was developed to assess the costs of removing small diameter timber from stands in the Pacific Northwest and was applied to volumes and acres in all western states. The resulting costs range from a low of $288 per acre in Utah's other softwood types to a high of $3,044 per acre in Utah's lodgepole pine type. Variations are due to slope and distances to mill differences across state and differences in treating various species groups in each state.

Trade between states and regions will occur when the net cost to an importing region is less than the cost of procuring logs locally. Thus transportation costs will be essential to development of trade patterns in the model. Following Fight (personal communication [May 2003]) and Rummer et al. [2003], we assume the cost of transporting wood between states is $0.35/bone dry ton (bdt) per mile or $1/mbf/mile. Distance from stump to mill is proxied by the distance to mill average in each state. Distances between states for trade purposes are determined by using the distance between spatial-center of forestland in each state.

TABLE 3. Delivered log prices and treatment costs by major species group by state.

State	Log price: Ponderosa pine	Log price: Lodgepole pine	Log price: Other softwood	Treatment cost: Ponderosa pine	Treatment cost: Lodgepole pine	Treatment cost: Other softwood
	$/thousand board feet			$/acre		
Arizona	43	39	200	1,796	1,632	383
California	300	280	400	1,139	1,208	2,398
Colorado	219	204	200	1,129	2,035	1,363
Idaho	493	460	400	816	2,286	1,314
Montana	493	460	400	816	2,286	1,314
Nevada	98	91	200	680	3,024	397
New Mexico	43	39	200	1,322	1,891	504
Oregon	528	493	400	1,020	1,847	1,728
South Dakota	219	204	200	994	2,035	1,368
Utah	98	91	200	680	3,024	288
Washington	528	493	400	1,020	1,847	1,728
Wyoming	98	91	200	994	2,035	1,368

Western U.S. spatial equilibrium model. The model is currently solved for a single representative period. We assess a five-year program but do not grow the stands, treated or untreated. The model maximizes western U.S. national forest acres treated in each year of a 5-year program subject to constraints. The acreage maximization occurs over all available acres in each forest type and condition class within each state. The objective function and constraints are shown in Table 4, the elasticities assumed are in Table 5 and a summary of the model simulations is in Table 6.

The model is solved first as a base case with the objective of maximizing social net welfare across all producers and timber consumers (summing across western U.S., western Canada and the rest of the world), not allowing mechanical fuel treatments and thus requiring no subsidy. Consistent with Samuelson [1952], social net welfare (SNW) is the sum of producer surplus plus consumer surplus minus transportation costs. In our case, SNW also includes government harvest and treatment revenues less government harvest costs and less the subsidy. National forest timber harvests are held constant, and a market equilibrium of private plus public production, consumption, and trade is found. For national forest timber, regardless of WUI, two sets of simulations were run, with each set including three condition class-restricted models. The first set modeled a \$1 billion subsidy without a limit on expenditures by state. The second set limited expenditures by state to a maximum equal to the proportion of timberland that state had in each condition class. The condition class-restricted models allowed treatments on (1) CC 3 only, (2) CC 2 + CC 3, and (3) all three condition classes. A similar set of simulations was done restricting treatment to only the designated WUI acres.

Products analyzed include softwood sawtimber and chips, and we allow for a maximum of a 30 percent outward shift in demand, i.e., demand capacity within a region can expand by 30 percent. Demand and supply elasticities with respect to price are inelastic and inventory supply elasticity is assumed to be one, Table 5. These elasticities are consistent with the published literature (Adams and Haynes [1980], Majerus [1980], Regional Forester [1984], Adams et al. [1986], Wear [1989], Adams et al. [1991], Newman [1987], Abt et al. [2000], Haynes et al. [2001]).

TABLE 4. Spatial equilibrium model objective functions and constraints.

Base Model	
Objective function	Maximize social net welfare = sum of producer surplus + sum of consumer surplus + government revenues from regular harvest − government harvest costs
Constraints	Public log export = 0. Harvest cannot exceed 1.3 times current harvest. Capacity utilization is limited to a maximum of 1.3 times current production and a minimum of .45 times current production. Treatments occur only on federal lands. Non-treatment government harvest is constant.
Acres Treated Models	
Objective function	Maximize acres treated.
Constraints	Above constraints plus limitations on treated acres by wildland urban interface class, condition class and state allocation.

TABLE 5. Demand and supply elasticities used to develop linear demand and supply functions at current prices and quantities.

		Other states:	California, Oregon & Washington
Softwood sawtimber	Supply with respect to price	0.3	0.43
	Supply with respect to inventory volume	1	1
	Demand with respect to price	-0.5	-0.5

TABLE 6. Summary of simulations for a five year mechanical treatment program of $1 billion per year. Simulations were run for all national forest lands and for WUI-only lands.

Label	Simulation description
Base	Maximize net social welfare, no treatments
No allocation by state	Subsidy allocation to states is unconstrained
CC3	Maximize treated acres on condition class 3 acres only
CC2+3	Maximize treated acres on condition class 2 and 3 acres only
CC1+2+3	Maximize treated acres on all condition classes
Allocation limited by state	Subsidy allocation to states is limited by proportion of state in each condition class
CC3	Maximize treated acres on condition class 3 acres only
CC2+3	Maximize treated acres on condition class 2 and 3 acres only
CC1+2+3	Maximize treated acres on all condition classes

The model has specific requirements for U.S. federal ownerships, recalling that treatments are allowed only on national forests. Public timber supply (nontreatment harvest) is assumed non-price responsive, and is held constant for the simulations. Export of logs from federal lands in both Canada and the U.S. is prohibited. Calculation of surplus from national forest harvests and treatments represents government revenues from sales less costs of treatment or harvest. We assume the current level of national forest harvest generates no surplus (revenues = costs), and use current cost/mbf as the cost of national forest harvest in all simulations.

Simulation results.

No wildland-urban interface constraints. The effect of the treatment program on private timber markets is broadly negative, Table 7, reducing SNW up to 3 percent in the western U.S. This effect is net of gains accruing to western U.S. timber consumers due to cheaper and larger aggregate log volumes entering mills, losses for western U.S. private timber producers due to lower prices and lower private timber harvests in response, the costs of wood transport, losses in the value of regular timber harvested from national forests also due to lower prices, and the cost to taxpayers of the subsidy. For example, under the scenario that limits treatments to stands classed as condition classes 2 and 3, losses in SNW amount to \$0.18B in the U.S. West resulting from treatment of about 787,000 acres. Relaxing constraints on condition classes to allow any condition class stand to be treated leads to similar losses. Timber consumers in the U.S. West are the primary beneficiaries of a treatment program, as prices drop and consumption increases, with gains ranging from \$0.50 to about \$1.01B, or 11 to 22 percent. Private producers in the U.S. West lose no more than \$0.46B in economic surplus, losses ranging from 11 to 22 percent. Their losses are due to price and output reductions. There are no impacts on Canadian markets and only small impacts on the rest of the world. Total program size would need to be greater than \$1.3B, mechanically treating and removing products on over 1.7 million acres per year, for Canadian markets to be affected.

When state-level restrictions on treatment subsidies are imposed, all of the effects of a treatment program are changed. Timber consumers in the western U.S. are benefited in a manner similar to an unconstrained

TABLE 7. Simulation outcomes under a base case with a social net welfare objective and six acreage maximization objectives where both WUI and non-WUI acres are treatable.

	Base case	Simulation—WUI + non-WUI acres					
		No allocation by state			Allocation limited by state		
		CC3	CC2+3	CC1+2+3	CC3	CC2+3	CC1+2+3
		Billion dollars					
Social net welfare, Western U.S.	5.93	5.98	5.75	5.80	6.08	5.88	5.77
Subsidy used	0.00	0.58	1.00	1.00	0.48	1.00	1.00
Govt. treatment revenues	0.00	0.30	0.53	0.53	0.30	0.55	0.51
Regular govt. harvest revenues	0.58	0.49	0.44	0.44	0.50	0.44	0.42
Regular govt. harvest costs	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Consumer surplus, W. U.S.	4.55	5.12	5.53	5.51	5.05	5.51	5.56
Private producer surplus, W. U.S.	2.05	1.80	1.59	1.61	1.81	1.60	1.61
Transport costs, W. U.S.	0.25	0.57	0.75	0.71	0.51	0.63	0.75
Consumer surplus, W. Canada	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Private producer surplus, W. Canada	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Consumer surplus, rest of the world	3.89	3.91	3.93	3.94	3.91	3.93	3.94
Producer surplus, rest of the world	15.42	15.40	15.39	15.37	15.40	15.38	15.37
		Acres					
Total area treated	0	435,986	786,676	939,773	388,658	773,776	912,645
Ponderosa pine	0	118,829	219,151	193,335	102,347	189,823	177,884
Lodgepole pine	0	70,623	79,633	7,623	46,976	79,614	19,871
Other softwood	0	246,534	487,892	738,815	239,335	504,339	714,890

program. Private producers in the region lose amounts similar to the allocation without state constraints. However, the amount of forest treated is also smaller when a state-level spending constraint is imposed. On average, imposing such a constraint reduces the area treated by about 11 percent, from 436,000 to 389,000 acres when only CC 3 lands are treatable; when all condition classes can receive mechanical fuel treatments, the effect of the constraint is to reduce the area treated by 3 percent.

Under this set of scenarios, not limited to wildland-urban interface forests, the area treated differs greatly across forest types, Table 7. Ponderosa pine types receive more treatment as the condition class constraints are relaxed from just CC 3 to CC2+3, with a smaller decline from CC2+3 to all. When less risky forest stands are included in the available treatable forests, lodgepole pine stands go largely untreated, while resources are devoted substantially to other softwood forest types and to ponderosa pine types.

As constraints on the condition class are relaxed to include all classes, treatments shift across states, Figure 2. States such as New Mexico, California, Arizona, Nevada and South Dakota experience smaller changes or even negative changes in treated areas as constraints on condition class are relaxed. The area added to the total mainly comes from Utah, Oregon, Colorado and Idaho which have an abundance of CC 1 land that can be cheaply treated and for which capacity constraints do not bind. When state-level treatment spending constraints are enforced, effects are reduced in Colorado and increased in Montana.

Wildland-urban interface constraints imposed. When treatment programs are limited to treating national forest lands in the West included in the wildland-urban interface, the market impacts and area treated are much smaller, Table 8. In this set of scenarios, the $1B subsidy available is never exhausted, i.e., it never binds in simulations. This keeps the annual cost of such a treatment program low and moderates the overall effects on welfare. For example, SNW, including government harvest revenues and costs, increases in the scenarios without state constraints, rising from about $5.93B to as high as $6.33B. By restricting the program only to the WUI, the treatments are concentrated in the higher WUI area states of Oregon, California and Washington. These areas are apparently the most profitably treated, leading to increases

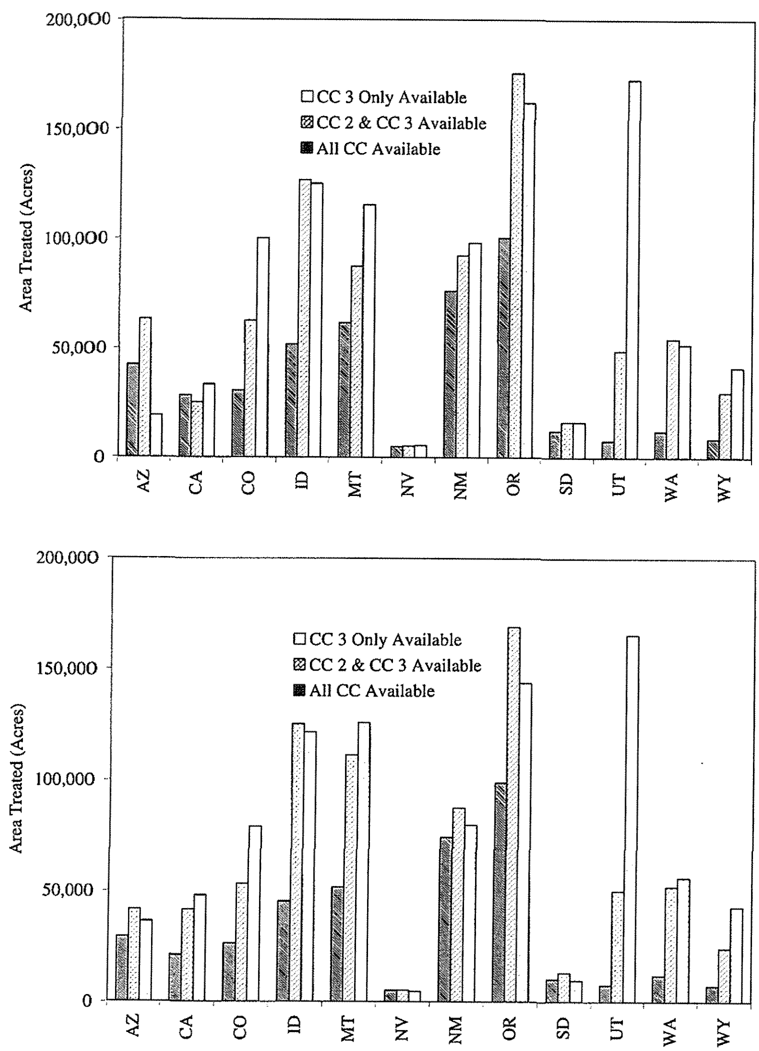


FIGURE 2. WUI and non-WUI area treated by state under alternative condition class constraints, without (top) and with (bottom), state-level treatment proportional constraints, under a treated acreage maximization primary objective, on national forests of the United States.

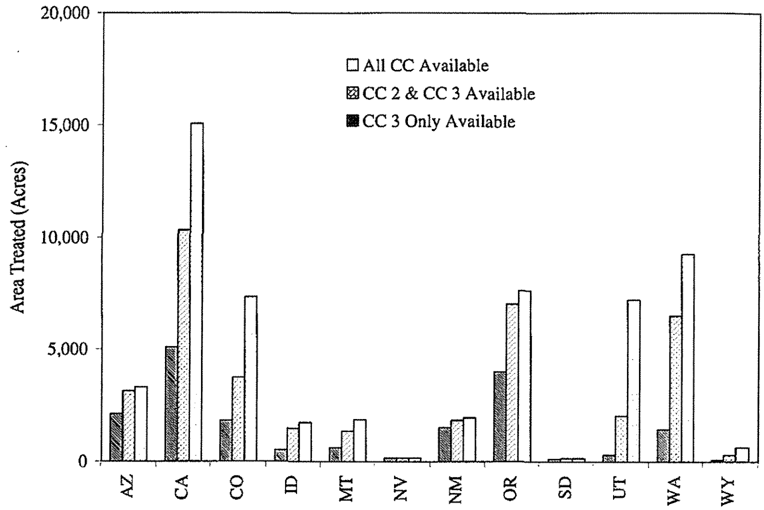
TABLE 8. Simulation outcomes under a base case with a social net welfare objective and six acreage maximization objectives where only WUI acres are treatable.

	Base case	Simulation—WUI + non-WUI acres					
		No allocation by state			Allocation limited by state		
		CC3	CC2+3	CC1+2+3	CC3	CC2+3	CC1+2+3
				Billion dollars			
Social net welfare, Western U.S.	5.93	6.30	6.29	6.31	6.33	6.29	6.33
Subsidy used	0.00	0.03	0.06	0.08	0.02	0.05	0.07
Govt. treatment revenues	0.00	0.02	0.06	0.08	0.02	0.05	0.07
Regular govt. harvest revenues	0.58	0.56	0.56	0.57	0.57	0.55	0.57
Regular govt. harvest costs	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Consumer surplus, W. U.S.	4.55	4.66	4.68	4.61	4.59	4.69	4.60
Private producer surplus, W. U.S.	2.05	2.02	2.00	2.01	2.05	2.01	2.02
Transport costs, W. U.S.	0.25	0.36	0.36	0.30	0.29	0.37	0.28
Consumer surplus, W. Canada	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Private producer surplus, W. Canada	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Consumer surplus, rest of the world	3.89	3.89	3.89	3.89	3.89	3.89	3.89
Producer surplus, rest of the world	15.42	15.42	15.42	15.42	15.42	15.42	15.42
				Acres			
Total area treated	0	17,806	38,088	56,351	15,314	33,452	49,276
Ponderosa pine	0	6,210	11,475	12,538	5,512	10,392	11,391
Lodgepole pine	0	1,973	4,059	6,530	1,474	3,116	4,801
Other softwood	0	9,624	22,555	37,283	8,328	19,944	33,083

in SNW deriving from higher consumer surplus but partially offsetting losses in producer surplus. Constraining by state reduced the size of the program and also the SNW. This could occur because the model is no longer selecting only the most profitable areas to treat.

Forest types receiving treatments reflect which kinds of treatable acres exist close to urban areas. In this case, the focus is on California, Oregon and Washington and increasing areas of lodgepole pine forests are treated. In fact, when all condition class constraints are relaxed, non-ponderosa forests get most of the treatment dollars allocated. The effects of the wildland-urban interface constraint on treatment leads to obvious biases in states receiving the bulk of the mechanical fuel treatments, Figure 3. These biases result directly from the amount of wildland-urban interface and the available capacity; large available capacities tend to limit the negative impacts of the treatment program. In this set of scenarios, states receiving the lion's share of the program are California, Washington and Oregon, with intermediate amounts going to Colorado and Utah. The program therefore leaves out the low population and low-capacity states of Nevada, South Dakota and Wyoming. Although Montana, Idaho and even Arizona have at least some capacity, their low amounts of national forest land with significant urban interface pressure means that they, too, get little of the subsidy under this scenario.

Conclusions. While mechanical treatments may not be the closest surrogate to wildfire in fire-prone areas, mechanical methods may be preferred to prescribed fire, for several reasons. Fire-related mechanical treatments are not constrained by the logistical difficulties of weather timing or by risk of damage to adjacent properties and do not create smoke, with its attendant air quality consequences. In addition, some have viewed broad-scale fuel treatments as potentially beneficial to timber markets, reinvigorating communities which in places of substantial federal forest holdings have been negatively affected economically by federal harvest reductions (Spelter et al. [1996], USDA Forest Service [2000], Paun and Jackson [2000]). However, treatment program administrators and timber market analysts should understand them as multifaceted, affecting fire risk, ecological values and the timber market. Finally, given that one focus of the Healthy Forest Restoration Act is to reduce fuels in the vicinity of communities at risk of catastrophic



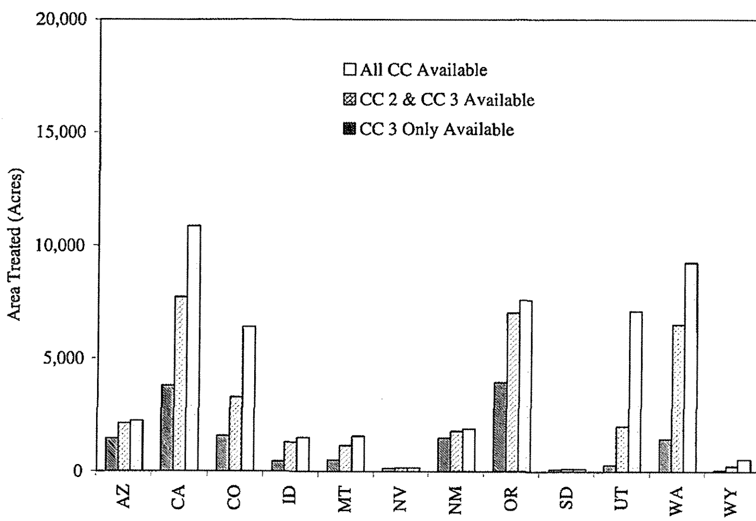


FIGURE 3. WUI-only area treated by state under alternative condition class constraints, without (top) and with (bottom) state-level treatment proportional constraints, under a treated acreage maximization primary objective, on national forests of the United States.

wildfires, such an analysis should evaluate the market impacts of imposing WUI-related constraints on program spending allocations. The research reported here is a first attempt to understand these issues.

Our analysis has shown that large scale programs of mechanical fuel treatments have the potential to influence the timber market significantly. With large fuel reduction programs, we find that timber consumer welfare in the western U.S. could be enhanced by up to 22 percent if managers were successful in implementing the program broadly across the region. On the other hand, private timber producers would face declines of up to 22 percent in welfare, but less in dollar value than consumers gain, due to lower production and prices. The revenues accruing to the U.S. Treasury through national forest harvests would increase, providing more payments in lieu of taxes for counties where treatments occur. However, the revenues would not rise by as much as the timber volume, since mill capacity limits would be quickly reached in certain locations and transporting some of the material out of the treatment zone is relatively expensive and therefore would not be economically feasible. Also, decision makers and land managers need to be cognizant of potential geographical inequities in such treatment programs across counties. For example, one county could receive much of the treatment and payments in lieu of taxes, due to its large federal holdings, while the neighboring county with mainly private lands could be negatively impacted by lower timber prices and lower output. From a broader geographical perspective, a program focusing on treating as many acres as possible under a fixed budget would result in certain states receiving most of the subsidy.

From the standpoint of treatment efficacy, a treatment program that reduced timber market welfare by these magnitudes should have fire effects and ecosystem restoration benefits that are at least equal to the market losses. Inclusion of the expected net benefits of the treatments in reducing aggregate losses and costs of wildfire may provide a different perspective on the value of a mechanical treatment program.

Large scale programs could have effects on our trading partners and other parts of the U.S. through output markets. Prohibitions against the export of softwood logs from public lands in the U.S. West mean that prices of timber decline when treatment removals enter markets. Hence, such a program has the potential, not simulated here, to affect the lumber market. U.S. domestic lumber manufacturers would find themselves in a more favorable position relative to competing Canadian softwood lumber producers, compared to no treatment program.

A program exclusively focused on the wildland-urban interface would have small impacts on western and non-western timber markets. If a program were implemented so that only WUI lands would receive treatments on national forest land, this program would be most active in California, Washington and Oregon. States such as South Dakota, Wyoming and Nevada would be essentially ignored. Utah would receive little treatment when only high-risk areas are treated but could get more attention if lower risk areas were treated. Our analysis did not address the potential benefits of a WUI-only program in terms of reducing the costs of wildfires. On the other hand, given that the budget for treatments in a WUI-only program never binds, it seems logical that the program evaluated in our research is not the kind that would be implemented. Instead, government would most likely create a program that imposes a WUI-first constraint.

This research leaves substantial room for further analysis. First, we confined our analysis to evaluating trade impacts with western Canada and the rest of the world. A more disaggregated analysis, at least quantifying effects in eastern Canada and the eastern U.S., could provide more relevant information for decision makers in government and forest industry. Second, this study assumed that treatment programs would add to regular timber harvest on federal lands. Further analysis would quantify how differing rates of substitution between regular harvest and treatment removals would affect treatment revenues, regular harvest revenues and the amount of treatments ultimately completed under a fixed budget. Managerial limits on federal lands lead to the expectation of at least some substitution. Third, our analysis was short-run and single-year, ignoring allocations over time and changes in demand capacity. The market effects of a treatment program could be smaller if the treatments were optimally spread out over time to maintain a desired maximum fire risk or fire fuel level. This model also ignored potential adaptations in timber demand, particularly capacity adjustments.

Fourth, a model that accounted for the potential differential costs of treatment in the wildland-urban interface compared to merely wildland forests would quantify the tradeoffs among alternative WUI-focused strategies. Fifth, our analysis was limited to national forest lands of the West, which is naive in at least one respect: much of the forests especially in need of risk reduction treatments are privately owned. An economic framework that could correctly describe a subsidy program for mechanical fuel treatments on private lands would need to account for externalities including free-rider behavior, adoption behavior and methods of encouraging optimal treatment patterns on the landscape. Sixth, our analysis used fire regime-condition classes as the yardsticks for prioritizing treatments across the U.S. West. Alternative approaches include treating stands to maximize fire risk reduction, or to maximize product volumes removed, or to maximize long-run net benefits.

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ENDNOTES

1. The National Fire Plan is available at: `http://www.fireplan.gov`.

2. The Healthy Forests Initiative is available at: `http://www.fs.fed.us/projects/documents/HealthyForests_Pres_Policy%20A6_v2.pdf`.

3. Healthy Forests Restoration Act, HR 1904, December 3, 2003. Available at: `http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=108_cong_bills&docid=f:h1904enr.txt.pdf`.

4. A collaborative approach for reducing wildland fire risks to communities and the environment: 10 year comprehensive strategy (8/2001) (`http://www.fireplan/gov/reports/7-19-en.pdf`) and Implementation Plan (5/2002) (`http://www.fireplan.gov/reports/11-23-en.pdf`).

5. We note here that integrated forest products firms, with both timberlands and mills, would be ambiguously affected by a treatment program—simultaneously reducing the value of their timber and also the price of log inputs to their mills.

6. In areas of high wildfire risk, biomass removals that are done at negative prices for the biomass may still yield positive net economic benefits for society, if treatment costs are less than benefits derived from reducing expected losses from wildfire. The payoffs from these kinds of biomass removals programs therefore require an analysis of the trade-offs of the program costs and expected wildfire net value changes.

7. Chip values from treatment harvests are small relative to log values. To the extent that treatments introduce these chips into markets, welfare of chip consumers, e.g., panel and pulp mills, and chip producers will be affected. We have found in initial analysis that chip market volume effects are second order to log market effects.

8. Cut and sold reports, National Forest System, Second Quarter 2003, available at: `http://www.fs.fed.us/forestmanagement/reports/sold-harvest/2003q1harv.shtml`. Accessed on October 6, 2004.

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